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Crowd Behavior Algorithm Development for COMBAT XXI

Connors, Casey; Hall, Steven; Balogh, Imre; Norbraten, Terry

TRADOC Analysis Center

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Crowd Behavior Algorithm Development for COMBATXXI

TRADOC Analysis Center
700 Dyer Road
Monterey, California 93943-0692

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LTC Casey Connors
Dr. Steven Hall
Dr. Imre Balogh
Terry Norbraten

TRADOC Analysis Center
700 Dyer Road
Monterey, California 93943-0692

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Dr. Imre Balogh
Mr. Terry Norbraten

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14. ABSTRACT
Our research is to develop a proof-of-concept constructive crowd behavior model using an agent-based simulation to represent various actions and reactions of crowds of non-combatants to military operations in an urban area. We show how to link this model with COMBATXXI at the application programming interface (API) level so that the model can be run in tight conjunction with COMBATXXI. TRAC and other anaytic organizations can use this type of crowd model to analyze many interesting questions. For instance, while conducting operational effectiveness analysis, this type of model can provide insights to questions of what effects large groups of civilians have on the effectiveness of weapons, equipment, and vehicles, or how our tactics, weapons, and operations effect the local civilian populace. This model begins to provide some quantification of the long term risk to operations that different interactions with large groupings of civilians on the battlefield bring, which in turn, inherently, reflects on the effectiveness of our doctrine, organizations, and materiel.

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Executive Summary

Overview

Our research is to develop a proof-of-concept constructive crowd behavior model using an agent-based simulation to represent various actions and reactions of crowds of non-combatants to military operations in an urban area. We show how to link this model with COMBATXXI at the application programming interface (API) level so that the model can be run in tight conjunction with COMBATXXI. TRAC and other anaytic organizations can use this type of crowd model to analyze many interesting questions. For instance, while conducting operational effectiveness analysis, this type of model can provide insights to questions of what effects large groups of civilians have on the effectiveness of weapons, equipment, and vehicles, or how our tactics, weapons, and operations effect the local civilian populace. This model begins to provide some quantification of the long term risk to operations that different interactions with large groupings of civilians on the battlefield bring, which in turn, inherently, reflects on the effectiveness of our doctrine, organizations, and materiel.

The Crowd Model

Previous research about crowds and crowd modeling explains many theories of how and why crowds form. Experiments have been conducted to better understand how to more safely control crowds of people. We use some of this theory to develop this proof-of-concept crowd model. This initial crowd model focuses on the main factors involved with interactions of military forces and crowds while those military forces are attempting some operation. There are several existing crowd models, which we briefly touch on in this document, but most of these models were developed either to loosely federate with training simulations, such as the Crowd Federate model, or for developing insights into crowd flow controls and emergency situations within a civil context. Our model's specific purpose is to tightly integrate with a combat model in order to provide insights into military-crowd interactions in a combat situation.

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Crowd Behavior Algorithm Development for COMBATXXI
Chapter 1
Introduction

Purpose

This report documents the Crowd Behavior Model for COMBATXXI developed by TRAC at Monterey and the Naval Postgraduate School. Our research develops a proof-of-concept model using a multi-agent-based simulation to represent various actions and reactions of crowds of non-combatants in an urban area. We also show how to link this model with COMBATXXI through the application programming interface (API) level.

Background

As the number and size of urban areas grows around the world and as a greater and greater percentage of the world's population resides in urbanized areas, questions pertaining to how the U.S. Army will operate within these expanded urban areas become more important. The June 2014 study conducted by the Chief of Staff of the Army's Strategic Studies Group, entitled "Megacities and the United States Army: Preparing for a complex and uncertain future," (Harris et al., 2014) poses many potential lines of investigation required to understand this complex urban environment more fully. To develop more robust models of urban environments in which to develop and test Army operations, we propose to improve the modeling of these environments in an impactful model. COMBATXXI (CXXI) is a combat model that has been used in a majority of Analysis of Alternatives in the JCIDS process for at least the past seven years. This combat model represents different features of combat entities from Brigade level down to individual Soldiers, and is an ideal simulation in which to develop a crowd behavior model.

Currently, most crowd or non-combatant models are focused on providing visual or auditory feedback to training (e.g. civilians in VBS3, a military simulation meant to train Soldiers in small unit tactics). Many of these models are not analytically oriented or empirically driven. Those models that are analytically oriented are focused on providing insights strictly within a civil context. A constructive crowd model is needed in order to meet the goal of improved urban environment modeling to study impacts of military operations in urban terrain. Impacts of crowds on military operations can include those lethality, mobility, survivability, etc., effects on a military force as well as second and third order effects on a local population in close proximity. A crowd model has the potential to answer questions about how an operation, or series of operations, can be affected by the need to cause a minimal impact to a local population in order to achieve strategic goals within the context of an operation.

Problem Statement

Develop a model of key behaviors of crowds of people in an urban environment to be implemented in a combat model such as COMBAT XXI for analysis of military operations interacting with urban populations.

Project Objectives

Overall, our goal is to show a method for constructing a model of the effects of military forces interacting with crowds of people in military operations. The primary objectives of this project are to:

- Model behavior of crowds or groups of people as they move throughout an urban environment; gathering, conducting a limited set of specific group actions, and dispersing; specifically during interactions with military forces conducting operations.

- Demonstrate some capabilities of this crowd behavior model within CXXI in several use case vignettes.

This version of our crowd model we construct is a proof-of-principle and a base for future work. Further work is required to validate this model and use it in production scenarios as described in the summary and conclusions.

Project Methodology

Figure 1 shows the methodology we used to develop our crowd behavior model. Our process consisted of three parts. We developed a conceptual model and defined required inputs and outputs for the model to work in conjunction with CXXI. We used a company level deliberate raid scenario based on a standard TRAC scenario(TRAC-WSMR, 2012), though we used an unclassified version of the scenario. Then we implemented the model. We used NetLogo, an agent-based modeling environment commonly used in social research, to construct our crowd model.

In the conceptual modeling phase, we limit our model to those inputs that are fairly well documented and easily implemented in an agent-based scheme. Our model uses distance measures between different agents as a proxy for several different cultural ideas and social norms. These inputs become the levers that can be accessed to drive the crowd behavior.

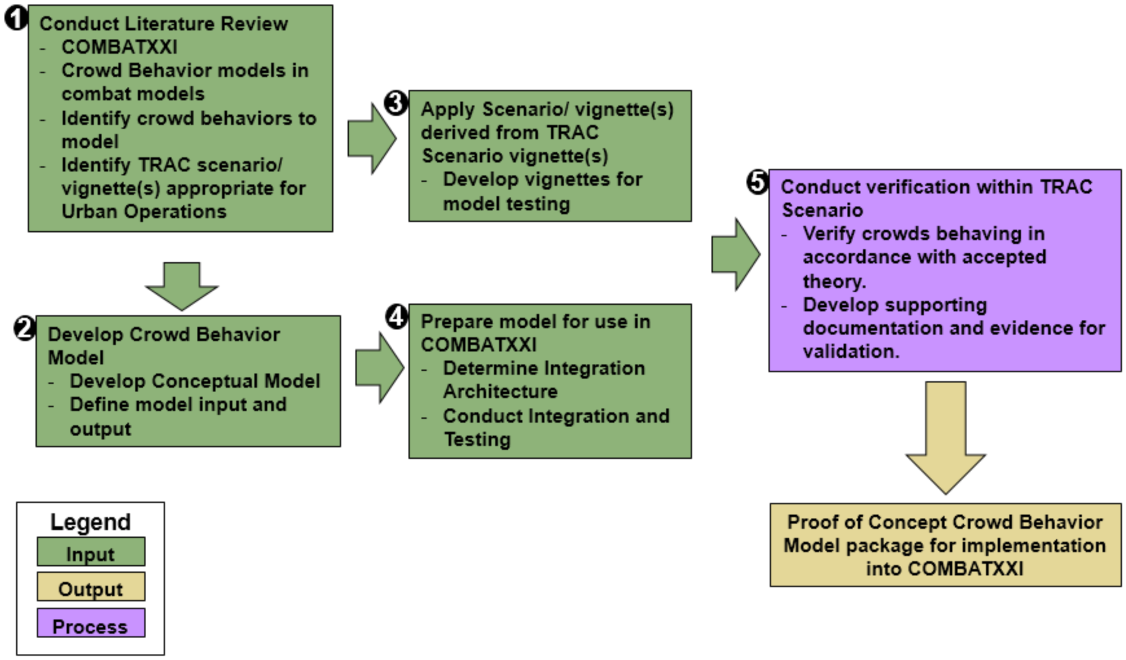

Figure 1. Crowd Behavior Model Development Methodology.

Once our crowd model was established in its base form in NetLogo, we developed linkages between the crowd model and CXXI that allow events involving crowds to flow back and forth between these two models in real time. This proof-of-concept is a demonstration of a crowd model that can communicate with a combat simulation, and a demonstration of a model that is easy to implement in new scenarios, with the primary concern being that it does not add significant amounts of time to scenario development for CXXI scenario integraters.

Report Organization

This report is organized into literature review, analysis, results, and summary and conclusions.

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Chapter 2
Literature Reveiw

What makes a crowd

Crowd Characteristics, Behaviors, 'Cultural' propensities, and Intentional Orientations

Crowds form for many reasons, from protests to simple gatherings at markets or places of interest, such as museums. The literature addresses many aspects of crowd dynamics. For instance, Berk (1974) illustrates a crowd that forms in protest of the U.S. strategic bombings in Vietnam. This work shows how the crowd character and intention flows over time. At the beginning, individuals are widely varied in their ideas about how to take action and whether action should even be taken. But then a few provide an idea and begin to take action which propagates and changes the idea throughout the crowd. Zeitz et al.(2009) present a gap in current theory-practice of crowd dynamics psychology and further show that two main attributes are needed in order to understand the motivation of a crowd: the "seed" or initiation of the intention that forms a crowd and the level of engagement that people in a crowd have with that seed. During research into the effects of non-lethal weaponry on crowds of people, Kenny et al. (2001) present key characteristics of crowds as shown through experimentation.

- Crowds are made up of individuals and groups of individuals that are not all alike in motivation.
- Crowds are made up of clusters of people, whether clustered by family, close relationships, ethnic or political idealogical similarities, which stay fairly close to each other and are influenced by each other.
- Crowd paticipants do not all agree with each other's motives for being there.
- Individuals in the crowd do not necessarily use the crowd to hide in order to protect their anonymity.
- Emotional displays from a full crowd are unusual.
- Crowd participants do not often act in unison.
- Crowds flow and change over time and in space.
- Crowds are not always violent and social, political, and economic factors do not necessarily predict whether a crowd will be become violent and for how long they will stay violent or riot.

Durupinar et al. (2008) also presents the non-homogeneity of crowds and constructs a simulation model which uses underlying driving parameters from the OCEAN personality model, which is general made up of five factors defined as openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism. Hassner, Itcher, and Kliper-Gross (2012) use movement vectors captured on full-motion video in real-time to classify crowd behavior and intentions. Helbing et al. (2005) shows how crowds flow in and around obstacles, such as hallways and along sidewalks. Luo et al., (2008) constructed what they termed a Crowd Federate Model simulation that uses social attachment theory. Attachment theory, which originated with John Bowlby, describes personal development in terms of emotional and physical attachments that individuals make with other people in their environment, particularly when they are maturing from childhood and centers on their primary caregivers. Similarly, Moussaïd et al. (2010) shows that crowds organize by groups within a crowd by relationships, such as freinds, family, etc., to a certain degree, something they term as communicative social interactions. Another researcher uses a simulation model to explore how individuals in a crowd act and react within the crowds environment from the perspective of creating a safer environment for the crowd (Still, 2000). He discusses the interaction of the variables of objective (or intent), motility (or ability to be in motion), constraint (rules or barriers placed on the crowd), and assimilation (the degree of homogeneity of the crowd over time).

The Crowd versus Authority dynamic

Key to understanding the complex influences operating between military (security) forces and the human civilian population groups that they increasingly must interact with is an understanding of the dynamic nature of the attachments human cognitive agents form to the various ‘social identities’ to which they are exposed. An interesting treatment of crowds in the context of networks and economics can be found in Easley and Kleinberg (2010).

For the purposes of our crowd model, the objective is to describe the interactions of a crowd and military forces. Crowds can be defined as people moving together in an area with at least one or more similar intentions. The military forces can be defined as representatives of the authority. Though, as the last decade of war has shown, U.S. military forces may not always find themselves in a situation where they are strictly operating as reprentatives of the local authority, members of a crowd may not see a difference, depending on the regional frame of the military operations taking place. Brooks et al. (2004) discusses interactions of military forces and crowds and how they use this to develop a better collateral damage estimator model within the Air Force agent-based systems effectiveness analysis simulation, SEAS, combat model.

Types of Crowds

Berlonghi (1995) describes the types of crowds as Spectator, Demonstrator, Escaping. These are grouped by action; Spectator crowds are those that might be present at a sports or music event or in a market place, Demonstrator crowds are the sort that are typcially associated with protestors or other types of political or social movements, and Escaping crowds are those that can be seen at the famous running of the bulls in Pamplona, Spain, or the sorts of crowds in which people are attempting to exit an area where an attack or other disaster occurred.

Momboisse (1967) classifies crowds as Casual, Conventional, Expressive, and Aggressive. These types are more expressive of the overall intention of the crowd.

Our crowd modeling research is primarily concerned with the presence of large numbers of civilians in the area of military operations, and thus needs to be able to represent crowds along the spectrum of intention and activity.

Crowd Modeling Efforts

The majority of crowd behavior research has been either for public safety applications or to create more realistic video games or training simulations. Several applications of these models are for analyzing safety in areas of high traffic, such as crowd flows on sidewalks or at public events. Akopov (2012) created a model primarily concerned with modeling crowds as indiviual agents in emergency situations involving attacks, explosions, fires and smoke, etc. This work modeled effects related to something they term the “turbulence of the crowd”. Cassol et al. (2016) model crowds for human safety analysis, specifically crowds egressing a building in the event of an evacuation. Other models are related to military operations, but are primarily used in training simulations or video games. For example, the Virginia Modeling, Analysis and Simulation Center at Old Dominion University developed a crowd behavior model for use with military simulations in the early 2000s called the Crowd Federate model (Petty et al.,2004; Nguyen, McKenzie, and Petty, 2005; Mckenzie et al., 2008; McKenzie et al.,2006). Today, this model has seen application mostly in conjunction with VBS2 and VBS3, which is an interactive simulation for training Soldiers to operate at the tactical level. In some other examples, Lau (2009) simulate crowds of characters to enhance realism of the characters during interaction with video game players, and Kim, Hoffmann, and Lee (2009) develop a crowd model to show more realistic crowds in video games.

Ivancevic, Reid, and Aidman (2010) develop a complex crowd model using entropy, again for application in crowd safety analysis. Kaminka and Fridman (2006) take an interesting approach by offering an algorithmic approach that adapts Festinger’s Social Comparison Theory (SCT). Musse and Thalmann (1997) use crowd modeling to visualize crowd movement in a generic setting and crowd movement within a museum. Finally, Wolinski, Lin, and Pettré (2016) establish a simulation of crowds that models the motion of inidividuals in the crowd according to probability fields that depend on the attributes of the agents and describe the agents probability of colliding while in motion.

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Chapter 3
Analysis

Operational Scenario

Our analytic scenario is a company deliberate raid vignette in which a military force conducts a raid on a compound to capture a high-value target. We use this scenario as it is already instantiated in COMBATXXI as an unclassified scenario using appropriate urban terrain maps. This scenario also represents a common operation that military forces at the small unit level conduct. As a part of the tactical operation, the military force implements a cordon around the objective in order to control the terrain within the objective. In this case the objective is a small compound that has three gates or openings in the wall for entering or exiting. Figure 2 is a screen shot of the compound where the green entities represent military force agents and the orange entities are local populace agents that coalesce into one or several crowds. These civilian agents attempt to enter the compound while the military force is conducting the raid, are curious about the military force, or any number of other actions that can be defined for the intent behind individual agent actions.

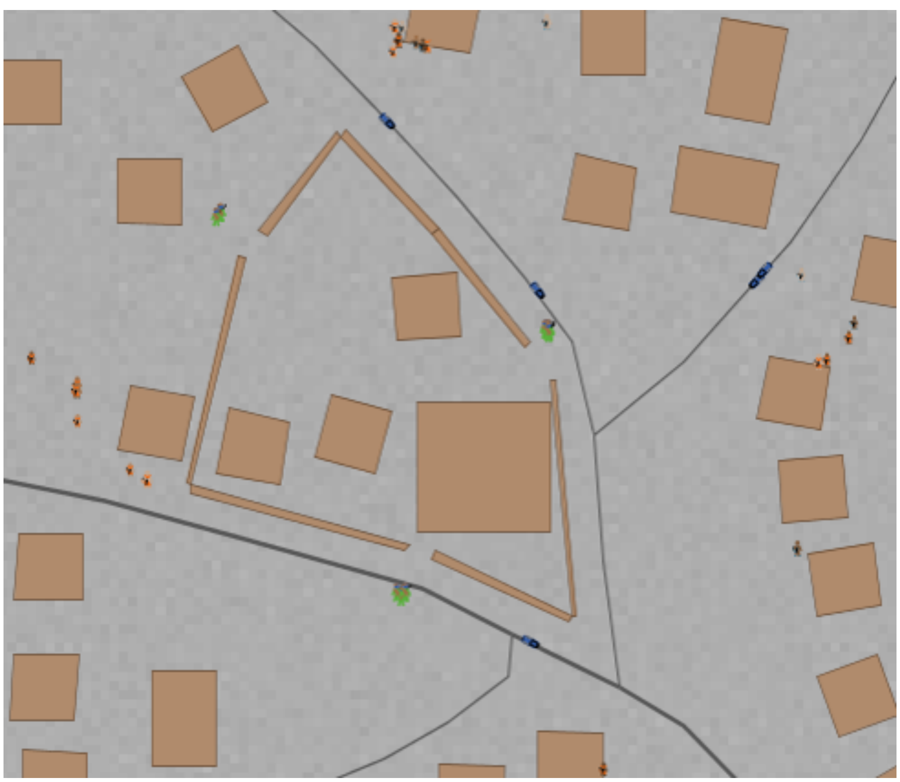

Figure 2. Company Raid Vignette Cordon.

Tactical Crowd Modeling Requirements

The intent of the Tactical Crowd Model is to provide support to analysts responsible for producing products supporting decision making in domains as varied as operational and tactical planning, JCIDS/DOTMLPF capability development decision-making, and doctrine/tactics development. Requirements for an analytically focused Tactical Crowd Model are categorized into three classes here: Performance Metric Driven Requirements; External Interfacing Based Requirements; and Validity Requirements.

For our initial proof-of-concept model, we use a limited number of controls and metrics to illustrate the benefits of the model. Because of this, our model is not appropriate to specific regions or operations. Rather more research is required to make this model a more generalized model, adding additional functionality to model crowd dynamics more closely. After that, each region requires further exploration, most likely by a social scientist, in order to adjust the model appropriately to a region, either through levers built into the model or by adding supplementary functionality to customize the model to a region.

The controls our model currently has implemented are:

- Family Relationships.
- Political/Ethnic Alliances.
- Attitude of crowd towards the military force.
- Attitude of the military force towards the crowd.
- Crowd desire to enter the compound being protected by the military force.
- Miltary force use of weapons against the crowd.
- Number of explicitly modeled agents.
- Ratio of genders male to female.
- Other initial crowd conditions (deployment, etc.).
- Other initial military force conditions (deployment, etc.).
- Inividual agents have a wide range of potential attributes including gender, age, ethnic and political affiliation, etc.

Performance Metric Driven Requirements

The foremost challenge of creating a crowd behavior model is to clearly articulate the range of objectives that our force or security units face when operating in populated environments. A clear articulation of these objectives is a prerequisite for defining the bottom line performance metrics that the Tactical Crowd Model is expected to produce and thus plays a major role in the necessary design of the model. The most important characteristic of the force unit's objectives with regards to the local population pertains to whether the population is the direct or indirect focus of the operation (e.g., the force's objective is part of a stability campaign's hearts and minds objective) or conversely whether the population simply poses a risk to the successful or effective completion of a non-population centric objective (e.g., the capture or securing of an asset). In practice, of course, many operations in populated regions involve elements of both population centric and non-population centric objectives. To this end, our initial metrics for this proof-of-concept model highlight a few useful measures that address different extreme aspects of either type of objective.

- Movement Delay
- Crowd Alienation
- Number of crowd agents that penetrate the cordon.
- Number of killed or injured crowd agents within each demographic defined in the model.
- Total demographics of each crowd.

External Interfacing Based Requirements

The Tactical Crowd Model is intended to support operational modes as both a stand-alone analytic support tool as well as serving as a component model within more encompassing, analytically oriented, modeling frameworks at the strategic, operational, or tactical level. This latter mode-of-operations provides the basis for an additional set of challenging requirements including both semantic and syntactic interface content requirements and simulation control requirements. Within the interface requirements, our focus is the capability to develop scenarios that integrate the crowd components without significantly increasing scenario development times. Therefore, the crowd model interface with the combat model, in our case COMBATXXI, must be simple to understand and easy to manipulate. This interface must also contain the controls necessary to develop different crowd postures, attitudes, and cultures very quickly in order to instantiate crowds into the scenario as easily as possible. These interfaces between COMBATXXI and our crowd model are described more fully in the results chapter.

Validity Requirements

Like all models, the value of this Tactical Crowd Model will be fundamentally determined by how readily the conditions under which it can be used to provide useful guidance can be successfully communicated. Defining the tool's validity domain involves both understanding the class of mission needs (and derived requirements) it can usefully address and the environmental circumstances (i.e., the scenario) in which each of those answers are reliable.

For the former, the class of mission needs addressed by this model is defined by interactions between military operations and the population. Wherever military operations come into close contact with a population, the same questions of operational effectiveness that TRAC typically analyzes are significantly influenced by the risk inherent to both current and future operations. Risk to these operations is affected by the challenges inherent in how these operations are undertaken while in the presence of a civilian populace. For example, a military operation, such as the raid scenario here, can be successful regardless of the civlian environment, so operational effectiveness of a particular weapon may not seem to depend on the civilian aspect. However, it seems logical that if this weapon is used without regard to the civilian populace, the risk exists that the population will become more hostile towards future operations in that environment and thus impact the succes of future raids. Within our model, we propose a way to measure that increase of hostility, and further propose that the model output for one military-civilian interaction may be used as input to our model for a sequential military-civilian interaction, thus providing decision makers with at least some idea of impacts to the new weapon technology effectiveness within a constrained battlefield. This is one example within the class of analytic questions and how this model may apply to operational effectiveness analysis. We do not explore validity in the class of analytic questions further, but leave this for future research.

The set of validity requirements that pertain to environmental circumstances is highly dependent on the particular socio-economic, political, and cultural environment of the region being studied in the scenario. Our research has found that crowd dynamics across different regions have many common factors, but also have many differences. Therefore, a general validity for the crowd model must be determined for only those factors that are common across different regions (e.g. cultures vary in terms of how far children are allowed to roam from their mothers). Our model in its current instantiation only includes a few of those general factors. This should be another area for future research to generalize the model. Additionally, because there are some differences across regions, at least some validity will have to be attained through a close look at each region on a case by case basis. Again, future research should determine how often the model should be validated for specific regional factors or what factors make a difference in crowd dynamics across different regions.

Chapter 4
Results

NetLogo Crowd Model Instantiation

NetLogo is a multi-agent modeling environment used extensively in research conducted concerning social interactions and influences. Our initial proof of concept models a "generic" crowd. Obviously to apply it to a specific region of interest requires consideration of cultural and social influences particular to that region. The internal structure of the model will likely require certain social science expertise to adapt the model to particular regions. The cultural and social influences are just too broad and particular to specific regions (based on our initial literature review) to include "culture" levers that can be manipulated by a general analyst. A much more general crowd model should be the subject of follow-on research to this project. Examples of the types of levers that may be more specific to a particular region of interest are things like women not allowed to drive or having to wear burkas and that effect on crowd dynamics, etc.

However, according to the literature there are factors that are general to all crowds. Such factors can be translated into controls that the analyst is able to manipulate. For instance, family relationships within a crowd, political alliances within a crowd, or the number of explicitly modeled agents, etc., are all general factors that can be controlled in our proof-of-concept model. Interpersonal distances between people are different in different cultures. These distances can be controlled in our model. Genders can be adjusted, so that if more men are found going to market in a particular culture, the analyst can put more male individuals in crowds in market areas. But these types of cultural, region specific behaviors have to be researched and verified in order for an analyst to use them in a valid manner, preferably by a subject matter expert who understands the region in which the scenario takes place.

Figure 3 depicts our crowd model in stand alone mode. This crowd model contains civilian members of a crowd, both female and male, each has attributes such as how old they are, what ethnic group they belong to, etc. Blue forces start in vehicles and then can deploy as individual Soldiers. Each of the Blue forces, or military forces, has the same types of attributes as the civilian entities.

Along the bottom of the visualization are the controls for the crowd and military force generating methods, i.e., the size of the crowds and military forces and where they are deployed by the model. The specific controls in this bottom panel include the density of the civilian population; the primary occupation of the civilian agents, which specifies the relative proportions of gender types, age categories and ethnicities as a function of the selected primary motivation for being 'on the street'.; the deployment of the crowd entities,

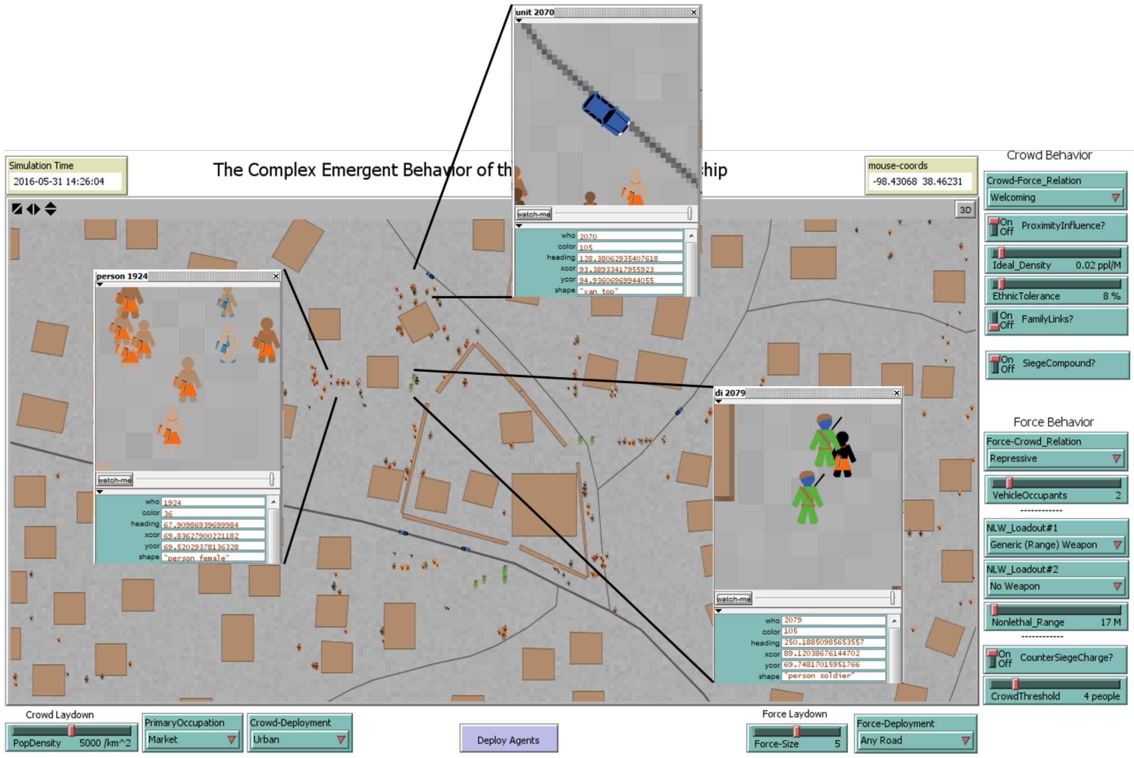

Figure 3. NetLogo Crowd Model Stand Alone.

which specifies the general locations where crowd elements are placed during setup; and finally, the military force size and deployment. Each of these controls can be manipulated in the base code to provide more or less specific options or provide more or less randomization to entity laydowns. For example, the crowd deployment is currently set for urban or rural, meaning that the crowds will either mostly be randomly placed in the urban areas or the rural areas on the map. The controls could be specified to certain grid coordinates such that a random number of the elements will be placed at those coordinates.

On the right side panel are controls that control the general behavior of the crowd and military forces. The crowd-force relation control determines how quickly interaction with blue forces causes alienation. For example, when set to welcoming, crowd alienation is only caused by hostile "charging" of members of the crowd (i.e. use of force, weapons, etc.), whereas a setting of fearful causes even the presence of an inhabited security force vehicle to result in crowd alienation. The proximity influence control tells crowd members to attempt to achieve ideal density, which is defined by the mix of distances that individuals attempt to maintain between other members of the crowd for various family, ethnic, and other reasons, and the degree to which individuals will follow each other around on the map. The ideal density control specifies the density of the crowd allowed, measured by people per square meter. The higher the number, the more densely packed the crowds become. The ethnic tolerance control sets the degree to which different ethinicities within the crowd influence each individual in terms of interpersonal disances and amount of desire to follow leaders in the crowd. A higher percentage means the individual agents are more tolerant, i.e. more influenced by ethnicities other than their own. The family links control causes children to remain closer to mothers. The siege compound control causes crowd agents to attempt to enter the compound. The force-crowd relation control determines how aggresively blue charges the crowd. This control requires development of behaviors to use non-Lethal weapons or lethal weapons. In our current instantiation, use of weapons is approximated by a “charge” of the crowd, i.e. the Blue force Soldier moves toward the crowd member. As an example, if the control is set to “Repressive”, the military force agents will “run” at the crowd members very aggressively. The vehicle occupants control determines the number of dismounts each blue vehicle carries. As stated, Non-lethal weapons controls are not yet implemented, as they will require both behaviors and effects to be modeled more extensively. The counter-siege control specifies whether blue forces dismount and protect the “gates” of the compound or not. The crowd threshold specifies the number of crowd elements that must be proximal to the “gate” before blue forces will react (charge) the crowd and force them away.

A set of external interface functions are provided in the CombatXXI_Interface_*.nls files that allow an external user to specify and create many of the agent creation functions defined above.

As a further note, within the crowd model, currently four different ethnicities are represented: A dominant ethnicity plus three sub ethnicities. In our model, when ethinc influence is turned on, ethnicities tend to flock together. These influences are currently based on a distance and weighted sum, but there are other algorithms that we could use.

Some outputs of the model are shown in Figure 4. Our proof-of-concept model uses some simple output metrics in order to illustrate the usefulness of this type of model. We show that movement delay to military forces when conducting an operation can be measured and output over time. Crowd alienation, which is currently a function of how many negative encounters with the military forces each agent in the crowd experiences, is a measure that can be carried over multiple military-crowd engagements within one scenario or multiple scenarios. Siege penetrators is simply the number of crowd agents that successfully make it through the military force cordon. This is a scenario specific measure and an example of how metrics of a crowd model can be adapted to specific scenarios. Crowd demographics, in turn, measures more quantitative, aggregate effects of the military operation on the crowds in the area of the operation.

Link NetLogo Crowd Model to COMBATXXI

Requirements for integration of a crowd model with COMBATXXI start with the requirements stated previously. Instantiation of a crowd in an existing dynamic scneario should not require a significant amount of additional development time and the crowd model itself must be fairly intuitive and easy to learn for analysts using the model within COMBATXXI. To that end, we developed further criteria for development of the model and linking it to COMBATXXI.

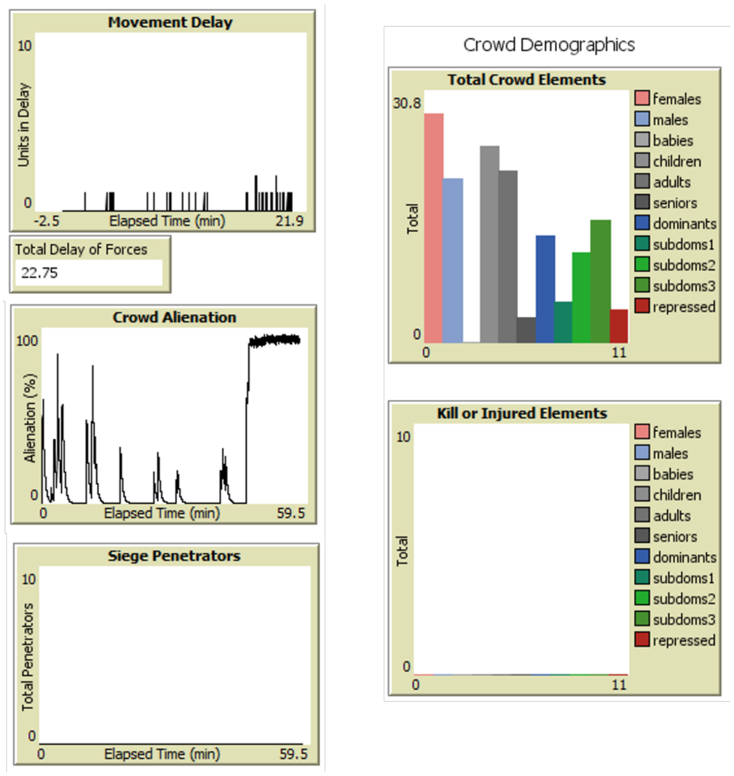

Figure 4. Crowd Model Example Output Metrics.

- Implementation of a tactical crowd model in a CXXI scenario should require minimal expertise in social science.
- Analysts will have several levers to manipulate crowd factors from within CXXI in order to implement the type of crowd in CXXI they need.
- Analysts will not require proficiency in NetLogo to implement a crowd model.

One challenge is to solve the communications of two complicated simulation models, one time-stepped (NetLogo) and one event-stepped (CXXI). Our solution is that CXXI controls the "Blue" military forces generally, and NetLogo controls the crowd, with control passing back and forth according to user defined event criteria. The COMBATXXI Model can now optionally run in tight conjunction with the NetLogo based 'Crowd Model'. COMBATXXI, representing the war-fighting entities, manages time until one or more entities encounters an urban area, whereupon the tactical crowd model is called. The crowd model is provided a time advance or mission objective to achieve along with a set of constraints to monitor and then the crowd model is allowed to advance its own clock. The crowd model stops and returns control to COMBATXXI when the objective has been achieved or when any of the monitored constraints is no longer satisfied. Objectives to be achieved and/or constraints to be monitored can be flexibly instantiated and specified via the API. Figure 5 depicts the two models running in conjunction as they conduct hand-offs of control of the military forces between events.

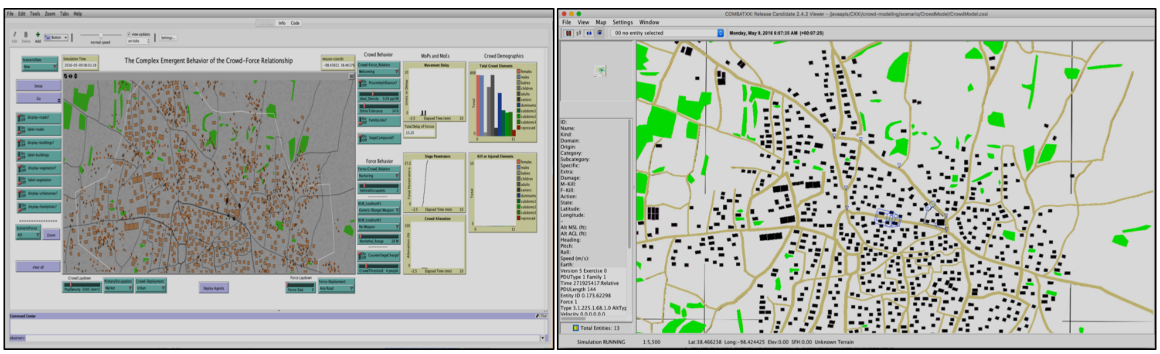

Figure 5. COMBATXXI and the Crowd Model Integrated and Running Side-by-Side.

Figure 6 is a visualization of the linkage between COMBATXXI and the Crowd Model within the API.

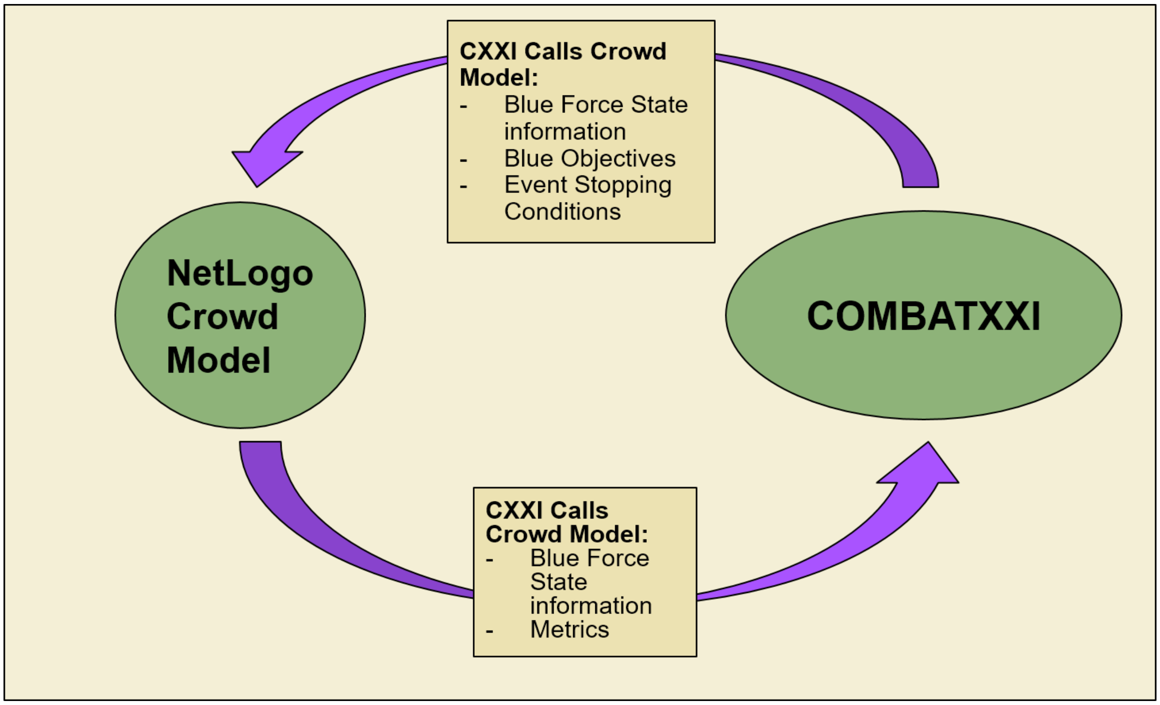

Figure 6. Linkage of COMBATXXI and the Crowd Model.

Our crowd model can be thought of as an object that COMBATXXI calls, with methods to both initialize and exercise or query the crowd behavior model, including the setting of state attributes that COMBATXXI is interested in having the crowd model explore. The crowd model takes state information from COMBATXXI and uses that in simulating the crowd elements and interactions. At the same time, the crowd model is its own simulation; control of blue forces is passed to the crowd model, and the crowd model goes back to COMBATXXI to report items of interest, such as delays or employment of weapons, as well as ending states of blue forces upon passing control back to COMBATXXI. This is so that the crowd model never has to go backwards. COMBATXXI, being event driven, populates its event list and tells the crowd model time-based stopping conditions or event based conditions, such as “when do Blue forces have a delay more then 15 minutes”. Importantly, once COMBATXXI starts running the crowd model, the crowd model continues to run, reporting to COMBATXXI those pieces of information that COMBATXXI has requested. The crowd model will interrupt COMBATXXI when an event of interest occurs telling COMBATXXI where crowds are located so COMBATXXI knows what events involve “running into” (i.e. interacting) with crowds.

Chapter 5
Summary and Conclusions

While this instantiation of the crowd model is not yet ready for use as a production quality model, it shows the clear potential for further development and confirms that an easy to use, impactful crowd model can be instantiated into COMBATXXI scenarios with little further scenario integration time.

Future work

In order to develop a more fully functional crowd model that analysts can use in studies, several lines of research are suggested.

- Enhance this crowd model with further crowd research, specifically into types of controls and factors that shape crowds. This includes validation of variations of this crowd model in various regional cutlural and political environments.
- Develop a crowd model module that can be easily incorporated in future studys and COMBATXXI scenarios.
- Conduct verification and testing. To include:
  - Verification that CXXI integration is providing consistent results.
  - Test outputs of data for consistency with current crowd dynamics theories.
  - Provide model to analysts at TRAC-White Sands Missile Range and measure their ability to implement the model in CXXI scenarios for current studies.

Additionally, future instantiation of this model can easily be translated from the NetLogo base code into other social networking agent based models, such as Repast.

Points of Contact

For access to the code base in NetLogo and the API's written to link the crowd model with COMBATXXI, please contact the MOVES Institute at the Naval Postgraduate School or TRADOC Analysis Center at Monterey.

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Appendix A
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Appendix B
Glossary

TRAC	Training and Doctrine Command Analysis Center
MTRY	Monterey
WSMR	White Sands Missile Range
COMBATXXI	Combined Arms Analysis Tool for the 21^{st} Century
CXXI	COMBATXXI
REPAST	Recursive Porous Agent Simulation Toolkit
VBS2/3	Virtual Battlespace 2/3
JCIDS	Joint Capabilities Integration and Development System
OCEAN	Openness to experience, Conscientiousness, Extraversion, Agreeableness, and Neuroticism personality model
SEAS	Systems Effectiveness Analysis Simulation